Load-Balancing in Heterogeneous Wireless Networks
Implementing a User-Centric Joint Call Admission Control Algorithm

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Abstract—Next generation wireless networks (NGWN) will be heterogeneous and it is envisioned that joint call admission control (JCAC) algorithms for NGWN will be user-centric. User centricity implies that users’ preferences are considered in making radio access technology (RAT) selection decisions. However, user-centric JCAC algorithms often lead to highly unbalanced network load, which in turn causes high call blocking probability and poor radio resource utilization. To address this problem, we propose dynamic pricing for balancing traffic load among available RATs in heterogeneous wireless networks utilizing a user-centric JCAC algorithm. By dynamically adjusting the service price in each of the available RATs, the proposed user-centric JCAC scheme evens out, as much as possible, the unbalanced traffic load caused by independent users’ preferences. The JCAC scheme uses fuzzy multiple-attribute decision-making technique to select the most appropriate RAT for each incoming call. We develop a Markov model to evaluate the overall call blocking/dropping probability, and percentage load in each RAT in heterogeneous wireless networks. Performance of the proposed JCAC scheme is compared with the performance of a scheme that does not incorporate dynamic pricing. Numerical results are given to show the effectiveness of the proposed JCAC scheme.

Index Terms—Call admission control, pricing, radio access technology, load balance, user’s preference, call dropping, call blocking, Markov model, QoS, mobile users.

I. INTRODUCTION

In heterogeneous wireless networks, mobile users will be able to communicate through any of the available radio access technologies (RATs) and roam from one RAT to another, using multimode terminals (MTs) [1]. In these heterogeneous networks, a joint call admission control (JCAC) algorithm is needed to decide whether a call will be admitted or not, and to select the most appropriate RAT for each admitted call.

It is envisioned that JCAC algorithms for heterogeneous wireless networks will be user-centric. However, user-centric JCAC algorithms often lead to highly unbalanced network load, which in turn causes high call blocking probability and poor radio resource utilization. To address this problem, we propose dynamic pricing for balancing traffic load in heterogeneous wireless networks where a user-centric JCAC algorithm is employed. The proposed JCAC scheme is designed to simultaneously achieve the following objectives in heterogeneous wireless networks:

1. Make RAT selection based on users’ preferences in order to enhance users’ satisfaction,
2. Dynamically adjust service price in each of the available RATs in order to distribute traffic load among the RATs,
3. Guarantee the QoS requirement of all admitted calls,
4. Prioritize handoff calls over new calls.

Uniform distribution of traffic load among multiple RATs in heterogeneous wireless network allows for a better utilization of the radio resources and reduces call blocking/dropping probability.

The contributions of this paper are twofold. Firstly, we use dynamic pricing to balance traffic load, as much as possible, among available RATs in heterogeneous wireless network implementing a user-centric JCAC scheme. This approach reduces overall call blocking/dropping probability and improves overall system utilization. Secondly, we develop analytical model for the proposed user-centric JCAC scheme, and derive new call blocking probability, handoff call dropping probability, and percentage system utilization in each RAT.

The rest of this paper is organized as follows. In section II, we discuss load balancing, users’ preferences, and pricing. In section III, we describe the system model and assumptions. The proposed user-centric JCAC scheme is presented in section IV. A Markov model is developed for the JCAC scheme in section V. In section VI, we investigate the performance of the proposed JCAC scheme through numerical simulations.

II. LOAD BALANCING, USERS’ PREFERENCES, AND PRICING

In this section, we discuss load balancing, users’ preferences, and pricing, and how they are interrelated in heterogeneous wireless network.

A. Load Balancing

Each RAT in heterogeneous wireless network has a maximum load capacity. If some RATs are overloaded whereas some other RATs are underutilized, it will result in poor utilization of radio resources. Balancing of traffic load among multiple RATs in heterogeneous wireless network allows for a better utilization of the radio resources [2].

Pillekeit et al [2] proposed a forced-based load balancing algorithm for co-located UMTS/GSM networks. The algorithm is triggered only when the differential load between the two networks is above a certain threshold. They simulate a scenario in which all UMTS and GSM cells are co-located and
all mobile phones use circuit switched voice service.

Gelabert et al [3] evaluate the performance of a load-balancing RAT selection algorithm for new calls in heterogeneous wireless network which consists of a UTRAN and a GERAN. They consider 7 collocated omnidirectional cells for GERAN and UTRAN.

In the two load-balancing JCAC algorithms discussed above, no analytical model is presented to investigate connection-level QoS (new call blocking probability and handoff call dropping probability) in heterogeneous wireless networks. Moreover, in the proposed algorithms, users’ preferences are not considered in making RAT selection decisions. In a heterogeneous wireless network, it is very necessary to consider users’ preferences in making RAT selection decisions.

B. Users’ Preferences

Next generation wireless network will be user-centric [4]. Therefore users’ preferences for a particular RAT should be considered in making call admission decisions. Users can set their preferences for a particular RAT on their mobile devices, and can even dynamically change their preferences with time. Examples of factors that determine users’ preference for a particular RAT are service price, date rate, battery power consumption, security level, etc.

Chan et al [5] presented a RAT selection algorithm based on the concept of fuzzy multiple objective decision making (MODM). Seven example criteria are used in the algorithm namely, signal strength, bandwidth, charging model, reliability, latency, battery status and the user’s preferred segment (priority).

Zhang [6] proposed a fuzzy multiple-attribute decision-making (MADM) RAT-selection method for handoff calls. The fuzzy MADM method operates in two steps. The first step is to convert the imprecise fuzzy variable to crisp numbers. The second step is to use classical MADM technique to determine the ranking order of the candidate networks. The highest-ranking RAT is then selected for the call.

In the user-centric JCAC algorithms discussed above, no analytical model has been developed to study connection-level QoS in heterogeneous wireless networks. Moreover, a major problem with the above JCAC algorithms is that they can lead to highly unbalanced traffic load among available RATs in heterogeneous wireless network because users act independently. Therefore, there is need for a mechanism that will even out the unbalanced traffic load caused by independent users’ preferences in heterogeneous wireless networks. In the following, we discuss pricing as a solution to the problem of highly-unbalanced traffic load in NGWN.

C. Pricing

Pricing in communication networks has received a lot of attention in the literature. In homogeneous wireless networks, it has been noted that network users act independently and sometimes “selfishly”, regardless of the prevailing network traffic conditions. Therefore, congestion has always been a problem in the network, especially during the peak period [7]. To avoid (or reduce) congestion, pricing has been used as a mechanism that give users incentives to behave in ways that improve the overall utilization and performance of the network.

Pricing mechanisms for wireless networks can be classified into static, dynamic, or auction-based schemes [8]. Static pricing is the simplest pricing policy, in which prices are fixed and independent of the state of the system [8]. In dynamic pricing, the network adapts prices as the traffic load changes. Prices rise in accordance with demand, deterring additional users from accessing the network or holding network resources for long periods, during congestion time. In auction-based pricing schemes, users attach a bid to each packet indicating the willingness to pay for the delivery of the packet, and the network serves packets in descending order of their bids.

Among these three classifications of pricing schemes, dynamic pricing is the most powerful and flexible mechanism [8]. In homogeneous wireless networks, dynamic pricing has been used to achieve a socially optimal bandwidth allocation maximize revenue, obtain an incentive-compatible class allocation, and achieve efficient power control [8].

Hou et al. [9] investigate the integration of dynamic pricing scheme with call admission control in order to efficiently and effectively control the use of resources in homogeneous cellular networks. Their results show an improvement in resource utilization.

In this paper, we apply dynamic pricing to balance traffic load among the available RATs in heterogeneous wireless networks where a user-centric JCAC scheme is employed. For any call arrival rates, the proposed JCAC scheme balance traffic load, as much as possible, among the available RATs in heterogeneous wireless networks.

III. SYSTEM MODEL AND ASSUMPTIONS

We consider a heterogeneous cellular network, which consists of \( J \) number of RATs with co-located cells, similar to [2, 3]. Cellular networks such as GSM, GPRS, UMTS, EV-DO, etc, can have the same and fully overlapped coverage, which is technically feasible, and may also save installation cost [10]. Fig. 1 illustrates a two-RAT heterogeneous cellular network.

In heterogeneous cellular networks, radio resources can be independently or jointly managed. We consider a situation where radio resources are jointly managed in the heterogeneous network and each cell in RAT \( j \) \((j = 1, \ldots, J)\) has a total of \( B_j \) basic bandwidth units (bbu). The physical meaning of a unit of radio resource (such as time slots, code sequence, etc) is dependent on the specific technological implementation of the radio interface. However, no matter which RAT (FDMA, TDMA, or CDMA) is used, we could interpret system capacity in terms of effective or equivalent bandwidth [11]. Therefore, whenever we refer to the bandwidth of a call, we mean the number of bbu that is adequate for guaranteeing the desired QoS for this call, which is similar to the approach used for homogeneous networks in [12].

Our approach is based on decomposing heterogeneous cellular network into groups of co-located cells. As shown in
Fig. 1, cell 1a and cell 2a form a group of co-located cells. Similarly, cell 1b and cell 2b form another group of co-located cells, and so on. Based on the following assumption commonly made in homogeneous networks, we assume that the types and amount of traffic are statistically the same in all cells of each RAT [12]. Therefore, the types and amount of traffic are statistically the same in all groups of co-located cells.

A newly arriving call will be admitted into one of the cells in the group of co-located cells where the call is located. When a mobile subscriber using a multimode terminal and having an ongoing call is moving from one group of co-located cells to another group of co-located cells, the ongoing call must be handed over to one of the cells in the new group of co-located cells. For example (Fig. 1), an ongoing call can be handed over from cell 2a to cell 2b or from cell 2a to cell 1b. Note that the handover consists of both horizontal and vertical handovers.

The correlation between the groups of co-located cells results from handoff connections between the cells of corresponding groups. Under this formulation, each group of co-located cells can be modeled and analyzed individually. Therefore, we focus our attention on a single group of co-located cells.

The heterogeneous network supports K classes of calls. Each class is characterized by minimum and maximum bandwidth requirements, arrival distribution, and channel holding time. Each class-i call requires a discrete bandwidth value, \( b_{i,w} \), where \( b_{i,w} \) belongs to the set \( L_i = \{b_{i,w}\} \) for \( i = 1, 2, ..., K \) and \( w = 1, 2, ..., W_i \). \( W_i \) is the number of different bandwidth values that a class-i call can be allocated. \( b_{i,1} \) (also denoted as \( b_{i,\text{min}} \)) and \( b_{i,W_i} \) (also denoted as \( b_{i,\text{max}} \)) are respectively, the minimum and maximum bandwidth that can be allocated to a class-i call. Note that \( b_{i,w} < b_{i,(w+1)} \) for \( i = 1, 2, ..., K \) and \( w = 1, 2, ..., (W_i - 1) \).

The proposed JCAC scheme always allocates the highest data rate available for new or handoff class-i call in the RAT in which the call is admitted. For example, in a two-RAT heterogeneous wireless network, if class-1 calls can be transmitted at the following two different bandwidth levels: 32 Kbps and 64 Kbps. Assuming that the highest data rate for class-1 calls supported by RAT-1 is 32 Kbps whereas the highest data rates for class-1 calls supported by RAT-2 is 64 Kbps. If a class-1 call is admitted into RAT-1, it will be allocated 32 Kbps whereas if the call is admitted into RAT-2, it will be allocated 64 Kbps.

Following the general assumption in cellular networks, new and handoff class-i calls arrive in the group of co-located cells according to Poisson process with rate \( \lambda^i \) and \( \lambda^k \) respectively. The call holding time (CHT) of a class-i call is assumed to follow an exponential distribution with mean \( 1/\mu^i \) [13].

To characterize mobility, the cell residence time (CRT), i.e., the amount of time during which a mobile terminal stays in a cell (same as the time it stays in a group of co-located cells) during a single visit, is assumed to follow an exponential distribution with mean \( 1/h \), where the parameter \( h \) represents the call handoff rate. We assume that the CRT is independent of the service class.

The channel holding time is the minimum of the CHT and the CRT. Because minimum of two exponentially distributed random variables is also exponentially distributed [14], the channel holding time for new class-i calls, and for handoff class-i call, is assumed to be exponentially distributed with means \( 1/\mu^i \) and \( 1/\mu^h \) respectively.

Note that this set of assumptions has been widely used for homogeneous networks in the literature, and is found to be generally applicable in the environment where the number of mobile users is larger than the number of channels [14].

IV. PROPOSED JCAC SCHEME

In this section, we describe the proposed JCAC scheme which consists of the following four components: joint call admission controller, call admission rate measurement unit, price-update unit, and bandwidth reservation unit. The components are connected as shown in Fig. 2, and are described as follows.

A. Joint Cal Admission Controller

The joint call admission controller implements the JCAC algorithm. The basic function of the JCAC algorithm is to make call admission and RAT selection decisions.

During call setup, a multi-mode mobile terminal requesting a service sends a request to the joint call admission controller which implements the JCAC algorithm. The service request contains the call type (new or handoff), service class, minimum and maximum bandwidth required, and weights assigned by the user to each of the RAT selection criterion. The weight is used in determining the user’s preference for a particular RAT. Based on the service request information, the JCAC algorithm decides which of the available RATs is most suitable for the incoming call and then notifies the mobile terminal of its decision. For an incoming new call, the response will either be “call accepted into RAT j \( (\text{RAT } j \in H) \)” or “call blocked” where \( H \) is the set of available RATs. For an incoming handoff call, the response will either be “call accepted into RAT j \( (\text{RAT } j \in H) \)” or “call dropped”.

The JCAC algorithm uses fuzzy MADM technique to select the most appropriate RAT for each user. Generally, fuzzy MADM technique consists of two stages [6]. In the first stage, fuzzy data are converted into real data. In the second stage, classical MADM is used to determine the ranking order of the available RATs.

In MADM problems, decision makers often need to select or rank alternatives that are associated with non commensurate and conflicting attributes. The decision makers’ preference information is often used to rank alternatives or select the most desirable one. There are many classical MADM methods such as SAW (Simple Additive Weighting), TOPSIS (Technique for
Order Preference by Similarity to Ideal Solution, AHP (Analytical Hierarchical Process), etc. The SAW method is the most widely used method. Therefore, we use the SAW method in this paper.

The JCAC MADM problem involves a set of J alternative RAT-j (j=1,2,...,J). These alternative RATs are to be evaluated for each arriving call with respect to a set of N criteria (or attributes), which are independent of each other. A decision matrix, D for J alternative RATs and N criteria is given as:

\[
D = \begin{bmatrix}
    c_{1,1} & c_{1,2} & \cdots & c_{1,N} \\
    c_{2,1} & c_{2,2} & \cdots & c_{2,N} \\
    \vdots & \vdots & \ddots & \vdots \\
    c_{J,1} & c_{J,2} & \cdots & c_{J,N}
\end{bmatrix}
\]

where \( c_{j,n} \) represents the performance rating of RAT-j (j=1,2,...,J) on criterion-n (n=1,2,...,N).

Each user would give his/her preference information for a network criterion by the user. In this paper, we use a 10-point scale (0,1,2,3,4,5,6,7,8,9) for weight assignments. For example, if a criterion is assigned weight 0 by a user, the criterion is considered to be five times more important to the user than criterion 1. If a criterion is assigned weight 0 by a user, the criterion is not important to the user, and therefore will have no effect in making RAT selection decision for the user.

Selection of the most appropriate RAT for each arriving call can be based on strict preference or flexible preference. In strict preference, the JCAC algorithm selects the highest ranking RAT for the incoming class-i call. If the highest ranking RAT cannot accommodate the call due to unavailability of radio resources, the call is blocked.

In flexible preference, the call is admitted into the highest ranking RAT which has enough radio resources to accommodate it. This implies that if the highest ranking RAT cannot accommodate the call due to unavailability of radio resources, the call is admitted into the next highest ranking RAT, and so on. The call is only blocked if none of the available RATs has enough bbu to accommodate the call.

### B. Call Admission Rate Measurement Unit

The call admission rate measurement unit (CARMU) measures the arrival rates of different classes of calls in each RAT. This measurement is done periodically. The CARMU also measures the residual capacity (bbu) available for each class of calls in each RAT. The measured values of call arrival rates and residual bbu are used by the price update unit to calculate the new price that will be used during the next period of time.

### C. Price Update Unit

The price update unit (PUU) periodically adjusts the service price in each RAT in the heterogeneous network. From the CARMU, the PUU obtains information about the residual capacity available for each class of calls, and the mean call admission rate in each of the RATs. Two price-update functions are considered for the proposed JCAC scheme. They are linear and exponential price-update functions.

### D. Bandwidth Reservation Unit

In order to maintain lower handoff dropping probability, we reserve certain bandwidth exclusively for handoff calls in all the cells of each group of co-located cells. The policy reserves bandwidth for aggregate handoff calls, thus giving them priority over new calls.

### V. MARKOV MODEL

The JCAC policy described in section IV can be modeled as a multi-dimensional Markov chain. The state space of the group of co-located cells can be represented by a \((2^K J)\)-dimensional vector given as:

\[
\Omega = (m_i, n_i) : i = 1, \ldots, k, \quad j = 1, \ldots, J)
\]

The non-negative integer \( m_i \) denotes the number of ongoing new class-i calls in RAT j, and the non-negative integer \( n_i \) denotes the number of ongoing handoff class-i calls in RAT j. Let \( s \) denote the state space of all admissible states of the group of co-located cells as it evolves over time. An admissible state \( s \) is a combination of the numbers of users in each class that can be supported simultaneously in the group of co-located cells while maintaining adequate QoS and meeting resource constraints.

The state \( S \) of all admissible states in the group of co-located cells is given as:

\[
S = \{ \Omega = (m_i, n_i) : i = 1, \ldots, k, \quad j = 1, \ldots, J) \}:
\]

\[
\sum_{i=1}^k m_i \cdot b_{i,j} \leq t_{i,j} \quad \forall \ j \quad \land \quad \sum_{i=1}^k (m_i + n_i) \cdot b_{i,j} \leq B_j \quad \forall \ j
\]

where \( b_{i,j} \) is the bandwidth allocated to class-i calls in RAT j and \( t_{i,j} \) is the threshold for rejecting new class-i call in RAT j.

The constraints simply state that during any period, T, the sum of the bandwidth units of all admitted class-i calls in each RAT-j cannot be more than the total bandwidth units available for that class of calls.

During period T, Let \( \rho_{new,i,j} \) and \( \rho_{han,i,j} \) denote the load generated by new class-i calls and handoff class-i calls, respectively, in RAT j. \( \lambda_{i,j}^n \) and \( \lambda_{i,j}^h \) denote the admission rates of new and handoff class-i calls in RAT j respectively.

Then,

\[
\rho_{new,i,j} = \frac{\lambda_{i,j}^n}{\mu_i^n} \quad \forall \ i, j
\]

\[
\rho_{han,i,j} = \frac{\lambda_{i,j}^h}{\mu_i^h} \quad \forall \ i, j
\]

From the steady state solution of the Markov model, performance measures of interest can be determined by summing up appropriate state probabilities. Let \( P(s) \) denotes the steady state probability that system is in state \( s \) \((s \in S)\). From the detailed balance equation, \( P(s) \) is obtained as:

\[
P(s) = \frac{1}{G} \prod_{i=1}^k \prod_{j=1}^J \left( \frac{\rho_{new,i,j}}{m_{i,j}!} \cdot \frac{\rho_{han,i,j}}{n_{i,j}!} \right) \quad \forall \ s \in S
\]
where \( G \) is a normalization constant given by:
\[
G = \sum_{s \in S} \prod_{i=1}^{3} \prod_{j=1}^{10} \frac{(\rho_{\text{new},i,j})^{m_{i,j}}}{m_{i,j}!} \frac{1 - (\rho_{\text{new},i,j})^{n_{i,j}}}{n_{i,j}!}
\] (6)

A. New Call Blocking Probability

Using strict preference for RAT selection, a new class-i call is blocked in the group of co-located cells if the highest ranked (selected) RAT-j does not have enough bbu to accommodate the new call. Let \( S_{d_i}^{j} \subset S \) denote the set of states in which a new class-i call is blocked in RAT-j. It follows that:
\[
S_{d_i}^{j} = \{ s \in S : (b_{i,j} + \sum_{x=1}^{k} m_{x,j} b_{x,j} > t_{i,j} ) \} \cup \{ s \in S_{d_i}^{j} : (b_{i,j} + \sum_{x=1}^{k} (m_{x,j} + n_{x,i,j}) b_{x,j} > B_{j} ) \}
\] (6)

Thus the new call blocking probability (NCBP), \( P_{b_i}^{j} \), for a class-i call in RAT-j is given by:
\[
P_{b_i}^{j} = \sum_{s \notin S_{d_i}^{j}} P ( s )
\] (7)

During period, \( T \), the overall call blocking probability of a new class-i call in the group of co-located cells is given as:
\[
P_{b_i} = \sum_{j=1}^{3} \frac{\lambda_{i,j}}{\sum_{j=1}^{3} \lambda_{i,j}} \cdot P_{b_i}^{j}
\] (8)

B. Handoff Call Dropping Probability

A handoff class-i call is dropped in the group of co-located cells if the highest-ranked (selected) RAT-j does not have enough bbu to accommodate the handoff call. Let \( S_{d_i}^{j} \subset S \) denote the set of states in which a handoff class-i call is dropped in RAT-j in the group of co-located cells. It follows that:
\[
S_{d_i}^{j} = \{ s \in S : b_{i,j} + \sum_{x=1}^{k} (m_{x,j} + n_{x,i,j}) b_{x,j} > B_{j} \}
\] (9)

Thus the handoff call dropping probability (HCDP) of a class-i call, \( P_{d_i}^{j} \), in RAT-j is given by:
\[
P_{d_i}^{j} = \sum_{s \in S_{d_i}^{j}} P ( s )
\] (10)

During period, \( T \), the overall handoff call dropping probability for a class-i call in the group of co-located cells is given as:
\[
P_{d_i} = \sum_{j=1}^{3} \frac{\lambda_{i,j}}{\sum_{j=1}^{3} \lambda_{i,j}} \cdot P_{d_i}^{j}
\] (11)

C. Percentage Utilization of Each RAT

During period, \( T \), the average utilization of each RAT-j in the group of co-located cells can be obtained by summing up for all the admissible state \( s (s \in S) \), the product of the system utilization of RAT-j in a particular state \( s (s \in S) \), and the probability \( P(s) \) of the system being in that state. The average utilization, \( U^{j} \) of RAT-j in the group of co-located cells can be derived as follows:
\[
U^{j} = \sum_{s \in S} P ( s ) \sum_{i=1}^{3} \frac{b_{i,j} (m_{i,j} + n_{i,j})}{t_{i,j}!} - (1 - (\rho_{\text{new},i,j})^{n_{i,j}})
\] (12)

Percentage utilization of each RAT-j in the heterogeneous wireless network is obtained as:
\[
\bar{U}^{j} = \frac{U^{j}}{\sum_{j=1}^{3} U^{j}} \times 100 \%
\] (13)

VI. NUMERICAL RESULTS

In this section, the performance of the proposed user-centric JCAC scheme is evaluated via simulation and is compared with that of a JCAC scheme that does not incorporate dynamic pricing such as previously proposed in [6]. We illustrate the proposed scheme using a three-RAT heterogeneous cellular network with subscribers having a single class of real-time calls that can be admitted with three different bandwidth levels. The calls are allocated 1bu (16 Kbps), 2 bu (32 Kbps), and 4 bu (64 Kbps) when admitted into RAT-1, RAT-2, and RAT-3 respectively. Four RAT-selection criteria are considered as shown in Table 1. We set the initial service price in each RAT to 0.5 cent per bbu per minute. The prices are periodically updated by the JCAC scheme.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Initial Price (C1)</th>
<th>Data rate (C2)</th>
<th>Security (C3)</th>
<th>Battery power consumption (C4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAT-1</td>
<td>0.5</td>
<td>1</td>
<td>medium</td>
<td>low</td>
</tr>
<tr>
<td>RAT-2</td>
<td>0.5</td>
<td>2</td>
<td>very high</td>
<td>high</td>
</tr>
<tr>
<td>RAT-3</td>
<td>0.5</td>
<td>4</td>
<td>high</td>
<td>medium</td>
</tr>
</tbody>
</table>

Other parameters used in the simulations are, \( z = 0.1 \), \( \lambda^{*} = 3 \), \( t_{1,1} = t_{1,2} = t_{1,3} = 10 \), \( B_{1} = B_{2} = B_{3} = 20 \), \( \mu_{1} = 0.5 \), \( h = 0.5 \)

In simulation scenario, weights assigned by users to each of the RAT selection criterion are randomly chosen from 0 to 9. Fig. 3 shows the performance of the proposed JCAC scheme with respect to call blocking/dropping probability.

Fig. 3. Call blocking/dropping probability versus price-update time
As shown in Fig. 3, \( Pb \) without DP and \( Pd \) without DP denote respectively, the new call blocking probability and the handoff call dropping probability of the JCAC scheme without dynamic pricing. \( Pb \) with DP-L and \( Pd \) with DP-L denote respectively, the new call blocking probability and the handoff call dropping probability of the JCAC scheme with dynamic pricing using linear price-update function. \( Pb \) with DP-E and \( Pd \) with DP-E denote respectively, the new call blocking and...
the handoff call dropping probability of the JCAC scheme with dynamic pricing using exponential price-update function.

It can be seen that for each of the JCAC schemes, Pd is always lower than the corresponding Pb. This shows that handoff calls are prioritized over new calls by using different call rejection thresholds for new and handoff calls. Note that lower Pd implies better connection-level QoS.

It can also be seen that both Pd with DP-L and Pd with DP-E are lower than Pb without DP. The reason is that JCAC with dynamic pricing is able to adjust the service price in each RAT with time so as to even out the unbalanced traffic among the available RAT. As a result, JCAC scheme with DP (using either linear or exponential price function) reduces the new blocking probability in the heterogeneous wireless network. For the same reason, both Pd with DP-L and Pd with DP-E are also lower than Pd without DP.

We also observe that for the proposed JCAC with dynamic pricing, using either linear or exponential price update function achieves similar results with respect to call blocking/dropping probability.

Fig. 4 shows the percentage of load (utilization) in each RAT for the JCAC scheme without dynamic pricing. For a given call arrival rate, we observe that the traffic load is highly unbalanced.

Fig. 5 and Fig. 6 show the percentage of load in each RAT for the JCAC scheme with dynamic pricing using linear and exponential price update functions respectively. As shown in Fig. 5 and 6, the proposed JCAC scheme with dynamic pricing tries to even out, as much as possible, the highly-unbalanced traffic load among available RATs with time.

VII. CONCLUSION

Dynamic pricing has been proposed to even out the highly unbalanced traffic load caused by independent users’ preferences in heterogeneous wireless networks implementing a user-centric JCAC scheme. By dynamically adjusting the service price in each of the available RATs, the JCAC scheme improves the distribution of traffic load among available RATs in heterogeneous wireless networks. The proposed JCAC scheme uses fuzzy MADM to select the most suited RAT for each incoming call thereby enhances users’ satisfaction. Using a Markov model enables us to derive new call blocking probability, handoff call probability, and percentage of system utilization in each RAT for the heterogeneous wireless network. We illustrate the performance of the proposed JCAC scheme using a three-RAT heterogeneous wireless network. Results show that the proposed JCAC scheme with dynamic pricing achieves lower call blocking/dropping probability than the JCAC scheme that does not incorporate dynamic pricing. Results also show that the scheme improves load distribution among available RATs in heterogeneous wireless network.

REFERENCES


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